

Grain Storage Methods and Their Effects on Sorghum Grain Quality in Hararghe, Ethiopia

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Abstract

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The majority of peasants in Hararghe, eastern Ethiopia, store sorghum grain in underground pits. These pits usually elevate grain moisture and storage temperature to levels that favour insect pests and fungi, causing grain spoilage. Information on pit environment, microflora association prior to storage, effects of storage methods, and changes in grain chemical components over time is sparse. The objectives of this thesis were to assess: (1) storage pit environment and grain weight loss; (2) mycoflora associated with grain prior to storage; (3) impact of storage methods on storage environment and grain quality; and (4) effects of storage methods, time and agro-ecological zones on grain chemical components. The reports in the thesis are based on field surveys in Hararghe districts, storage experiments and laboratory analyses.

Mean storage pit temperature in seven districts ranged from 24.5 to 33.3 °C while the mean grain moisture varied from 15 to 17% after 7 to 9 months. The mean relative humidity in pits of the districts ranged from 58.3 to 86.1%. The grain bulk density decreased by 4% in 7 months. The district mean grain weight loss varied between 2 and 13% for the same storage period. Mean germination in the districts decreased from 83 to 27% in 7 to 9 months. Frequencies of *Aspergillus* and *Penicillium* species increased over time on grain stored in soil pits in the districts.

Field fungi including *Alternaria*, *Cladosporium*, *Fusarium*, and *Phoma* species were associated with the grain in Alemaya prior to storage. Trace *Aspergillus* and *Penicillium* species were detected in association with the grain in some sampling sites prior to storage. Frequency of *Penicillium* species increased over time.

Granary temperature and grain moisture content were higher in the soil pits than in the above-ground bins, and cement- and dung-lined pits at Alemaya University. The grain bulk density of samples from the soil pits decreased by 9% in 17 months while the changes in the other three store types were not significant. Germination of grain from the soil pits decreased by 6% per storage month while no significant difference was detected among the above-ground bin and non-soil pits.

Soluble carbohydrate contents decreased from 2.4 to 1.2% in 7 to 9 months for samples from Hararghe districts and from 2.4 to 1.9% in 7 months and to 0.97% in 17 months for samples from soil pits at Alemaya University. The organic matter content decreased from 97.8 to 91.6%; and the crude protein increased from 10.1 to 11.2% in 17 months in samples from soil pits at Alemaya University. Storage fungi were associated with grain from the soil pits. Use of improved above-ground bins and/or modified underground pits is required to maintain the grain quality and to extend storability.

Keywords: *Aspergillus*, bulk density, chemical components, humidity, germination, storage methods, moisture, mycoflora, *Penicillium*, pit, sorghum grain, storage fungi, temperature

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Dedicated to

my grandmother w/ro Aberash Agegnehu

and

my wife w/ro Alemtsehay Berihun

Contents

Introduction.....	7
Sorghum as cereal staple crop.....	7
Storage in traditional underground pit and its problems.....	7
The rationale for research on underground storage pit.....	9
Objectives.....	10
Materials and Methods.....	10
Assessment of sorghum storage environment and stored grain loss in Hararghe, eastern Ethiopia.....	10
Assessment of mycoflora on sorghum grain in Alemaya district prior to storage	11
Above-ground bin and underground pit experiment at Alemaya University.....	13
Chemical component analyses of stored sorghum grain.....	14
Statistical analyses of research data.....	15
Results.....	16
Pit environment, grain quality and associated mycoflora in Hararghe districts.....	16
Mycoflora association with grain during pre-harvest and prior to storage.....	17
Impact of storage methods on pit environment and sorghum grain quality.....	17
Effects of storage methods, storage time and agro-ecological zones on chemical components.....	18
Discussion and Conclusions.....	18
Future Research Priorities.....	21
References.....	22
Acknowledgements.....	26

Appendix

Papers I-IV

The present thesis is based on the following papers, which will be referred to by their Roman numerals:

- I. Dejene, M., Yuen, J. and Sigvald, R. Assessment of sorghum storage environment and stored grain loss in Hararghe, eastern Ethiopia (Submitted).
- II. Dejene, M., Yuen, J. and Sigvald, R. Assessment of mycoflora on sorghum grain in Alemaya district, eastern Ethiopia, prior to storage (Manuscript).
- III. Dejene, M., Yuen, J. and Sigvald, R. 2004. The impact of storage methods on storage environment and sorghum grain quality. *Seed Science and Technology* 32 (In press).
- IV. Dejene, M., Yuen, J. and Sigvald, R. 2004. Effects of storage methods, storage time and different agro-ecological zones on chemical components of stored sorghum grain in Hararghe, Ethiopia. *Journal of Stored Products Research* (Accepted).

Introduction

Sorghum as cereal staple crop

Sorghum (*Sorghum bicolor* (L.) Moench) is an important source of food, feed and forage worldwide (ICRISAT, 1980). In Africa and Asia, it serves as a staple food for more than 200 million people, and the total cultivated area is surpassed only by rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) (Hepperly, Filiciano & Sotomayor, 1982). It is the fourth important staple crop both in cultivated area and in total grain production among the major five cereal crops produced in Ethiopia, preceded by *teff* (*Eragrostis tef* (Zucc.) Trott.), maize, wheat and followed by barley (*Hordeum vulgare* L.). The cultivated area covered by sorghum in Ethiopia is estimated at 995000 ha and the national average yield is 1.2 t ha⁻¹ (CSA, 2000). Sorghum can grow under adverse soil, climatic, and poor management conditions in a wide range of elevations from lowlands to highlands in the country and can supply food in drought prone areas (Stemler *et al.*, 1977; Brhane, 1980, 1981a, 1981b, 1982; Hepperly, Filiciano & Sotomayor, 1982). This cereal is the major food crop in Hararghe, eastern Ethiopia, followed by maize. It covers 87000 ha (48% of cultivated temporary crops) in East Hararghe and 65000 ha (42% of cultivated temporary crops) in West Hararghe with a total annual grain production of 223000 t in the region (CSA, 2000). In this region, it is mainly intercropped with maize and often intercropped with haricot beans (*Phaseolus vulgaris* L.), groundnut (*Arachis hypogea* L.) and *chat* (*Catha edulis* (Vahl.) Forsk.). The sole sorghum flour or mixed with other cereal flour is used for making *injera* (local circular-pancake that serves for preparing *lafiso* in Hararghe), porridge, and leavened bread (Brhane & Belaynesh, 1981; Belaynesh, 1982) while the whole grain may be roasted or boiled with other cereal and/or legume grain and consumed.

Storage in traditional underground pit and its problems

Farmers in the central, northern, southern and western parts of Ethiopia commonly store their seeds and grains in the above-ground bin locally known as *gotera*, which is made of bamboo sticks, wood and/or mud (Gilman, 1968). However, the overwhelming majority of peasants (more than 70%) in Hararghe store their sorghum, and sometimes even maize, in the flask-shaped traditional underground storage pits of variable dimensions until it is consumed or sold when the grain market improves (Gilman, 1968; Boxall, 1974; Gilman & Boxall, 1974; Niles, 1976; Solomon, 1983; Lynch *et al.*, 1986). The storage pits are usually dug in sandy or stony soils with gentle topography and where there is less water drainage problem and less hazard of soil collapsing into the pits. Justifications given by farmers for this type of storage include protection from fire, theft, insect pests, and domestic and wild animals. The low cost of pit preparation, especially in places where wood for above-ground bin construction is not available, is mentioned as an economic reason. Farmers also believe that grain stored in underground pit is blessed by God and bountiful. The storage pits are mostly neither lined nor plastered with any material that would reduce moisture migration into the stored grain (Gilman, 1968). The contact of the grain with wet inner pit walls often leads

to moisture ingress into the inter-granular space elevating both the grain moisture content and the relative humidity inside the pit. Besides, respiration by insect pests, mainly *Sitophilus*, *Sitotroga* and *Tribolium* species, micro-fungi, other micro-organisms and the living grain itself produces high temperature and water activity (Adams, 1977; Neergaard, 1977; Bothast, 1978; Meronuck, 1987; Prasad, 1992; Copeland & McDonald, 1995). Such a pit environment leads to moulding and grain deterioration (Shashidhar, Ramakrishna & Bhat, 1992). The grain stored in the underground storage pit is often mixed with collapsing soil from the walls and this affects its purity, market and nutritional values. It is also inconvenient to remove grains for consumption or sale at frequent intervals.

Grain loss during and after harvest is a major problem in agricultural production in developing countries. Insect pests, rodents, and micro-organisms comprise the larger proportion of post-harvest losses. Storage fungi are known to be the dominant causes of post-harvest deterioration of cereals, legumes and oilseeds in the world (Janicki & Green, 1976; Bothast, 1978), mostly *Aspergillus* and *Penicillium* species (Wallace, 1973; Christensen & Kaufmann, 1974; Mathur & Jørgensen, 1992; Shashidhar, Ramakrishna & Bhat, 1992). Although post-harvest grain loss estimates are either scanty or lacking for most of the cultivated crops in Ethiopia, some research has been conducted in Hararghe with the prime objective of identification of sorghum storage problems (Gilman, 1968; Boxall, 1974; Niles, 1976; Solomon, 1983; Lynch *et al.*, 1986). A number of *Aspergillus* and *Penicillium* species are found associated with sorghum causing severe grain deterioration (Niles, 1976). The sorghum grain loss due to moulding in Alemaya was estimated to range from 2 to 25% for full pits and 7 to 35% for half full storage pits (Gilman, 1968; Niles, 1976; Lynch *et al.*, 1986). Grain losses vary from one geographic location to another and from pit to pit, depending on original grain conditions, season, and associated organisms. Losses could be even higher if aggravated by high initial grain moisture content, direct rainwater leakage into the store, pest infestation, and poor storage sanitation.

The respiration by organisms associated with the grain and the living grain itself elevates the carbon dioxide, relative humidity, and temperature levels inside the storage environment, even to the extent of the process called “*grain heating*” (Christensen & Kaufmann, 1965). In turn, the high temperature and the concomitant high relative humidity in the store reduce seed viability due to an increased degree of invasion by storage fungi (Qasem & Christensen, 1958; Fields & King, 1962). Such invasion of sorghum and maize seed by storage fungi will result in reduction in seed germination and discoloration of the germs (López & Christensen 1963, 1967). Severe invasion also leads to other tremendous quantitative and qualitative grain deterioration including low nutritive value, moulding, mustiness, mycotoxin production, offensive odour, rancidity, seed-cake and grain weight loss (Niles, 1976; Neergaard, 1979; Prasad, 1992; Brown *et al.*, 1995). Farmers in Hararghe are often tempted to reject a significant proportion of their grain due to moulding. This grain required a lot of labour, money, time and related resources to produce. The situation is intolerable since it has a direct link with shortage of grain and human starvation in the region.

The rationale for research on underground storage pit

The information on traditional underground storage pits in Hararghe is very scanty. It is not well known how long a farmer can keep his grain in the underground pit without deterioration. The patterns of granary temperature, relative humidity, grain moisture contents, and association of microflora with sorghum grain stored in underground pits under different agro-ecological conditions are not documented. The changes in grain bulk density, grain weight loss, seed germination, and chemical components of sorghum grain stored over time are not estimated. Information is meagre on source of grain contamination by storage fungi prior to grain storage. It is not certain where and when the storage fungi commence grain contamination and flourish later during storage. The effects of lining methods of underground pits on pit environment, mycoflora development, grain quality and storability are not identified. A thorough comparative investigation of above-ground bin and underground pit storage has not been conducted to look into their impacts on grain quality and storability. The availability of such information would enable us to predict the allowable safe storage times (Sinicio, Muir & Jayas, 1997).

Today, more than ever, safe grain storage and prevention of post-harvest losses by farmers has become more a necessity than a rule to overcome shortage of grain and to tackle starvation and hunger in Ethiopia. This is crucial to ensure food security and to feed the ever-increasing population (currently over 72 million increasing at a rate of 3%) of the country where more than 85% of the broad mass of the population earns its livelihood directly or indirectly from agriculture. Minimizing the post-harvest grain losses due to destructive agents such as storage fungi needs due attention by researchers, grain managers, farming community and consumers. The need for maintenance of the grain nutritive and other inherent qualities through improved storage methods and/or modified underground pits is unquestionable and timely. This grain storage study provides data on the underground pit storage environment, source of inoculum for contamination, extent of sorghum grain damage expected, storability of grain in safe conditions, most affected grain parameters resulting from poor storage, changes in chemical components over time, and mycoflora associated with the grain. These data would give hints to grain managers with reference to the need for designing storage structures that maintain low temperatures and grain moisture contents at levels safe for reasonably long grain storage.

Objectives

The major objective of the study was to generate quantitative data on the above-ground bin and underground storage pit environment and related sorghum grain quality. The specific objectives were to:

1. assess sorghum storage environment and stored grain loss in Hararghe, Ethiopia (**Study I**)
2. assess the mycoflora on sorghum grain between pre-harvest time and prior to storage (**Study II**)
3. determine the impact of storage methods on storage environment and grain quality (**Study III**)
4. study effects of storage methods, time and different agro-ecological zones on grain chemical components (**Study IV**)

Materials and Methods

Assessment of sorghum storage environment and stored grain loss in Hararghe, eastern Ethiopia

The survey was conducted in seven districts of Hararghe, eastern Ethiopia (Figure 1, 2, and 3), representing lowlands (Hundenie and Miesso), intermediate (Babile, Kersa and Tulo) and highlands (Alemaya and Chelenko) during February to August in 2001. The lowlands are characterized by hot climate and short rainy season with rainfall deficiencies for crop production. The highlands experience high annual precipitation and cool climatic conditions during and towards the end of the rainy season. The intermediate lands have climates between the two extremes. Grain samples were removed, with sampler at two-month intervals, from the underground pits of four voluntary farmers in each district. The temperature and relative humidity in the storage pits were measured with a thermo/humidity metre immediately after partial pit opening at subsequent samplings. The grain moisture contents were measured with a digital seed moisture metre soon after grain removal from pit. The storage pit dimensions were also measured in the selected survey sites.

The grain bulk density or standard volume weight (svw) was measured using a hectolitre weight (Harris & Lindblad, 1978). The thousand-grain test weight was weighed with a sensitive balance. The grain weight loss due to moulds was calculated using the thousand grain mass (TGM) method developed by Proctor & Rowley (1983), mentioned under 'statistical analyses'. Standard procedures were employed to test seed germination (ISTA, 1985, 1996; Mathur & Jørgensen, 1992). Two hundred kernels were divided into four parts as replicates, arranged on moist germination paper in bowls, watered with distilled water and placed on a table at room temperature (20-22 °C). Germinated seeds were counted eight days after planting. The heights of 25 seedlings per replication, i.e. 100 seedlings per sample, were measured 12 days after planting. The fresh and dry root and shoot weights of the same 25 seedlings were also taken separately with sensitive balance

with the aim of judging the relative germination vigour (Follstad & Christensen, 1965).

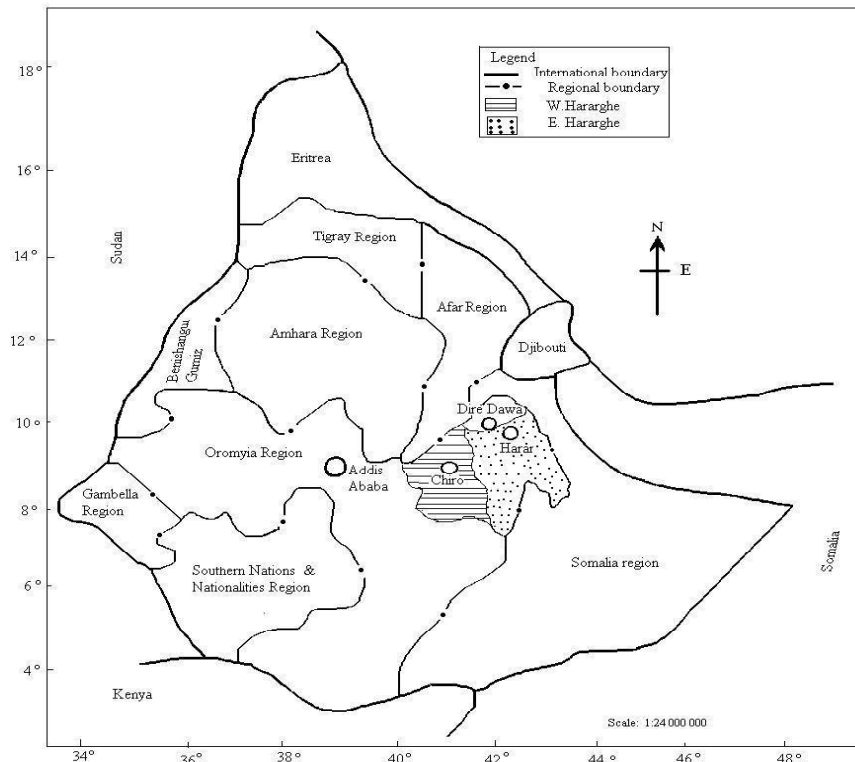


Figure 1. Map of Ethiopia indicating survey zones of Hararghe region.

Malt extract agar (MEA) with 75 g sodium chloride (7.5% NaCl) per litre agar solution was used to detect the mycoflora associated with the grain (Boller & Schroeder, 1974; Samson *et al.*, 1996). Fifty kernels per sample were surface-sterilized by soaking for 2 minutes in a 0.5% chlorine solution of sodium hypochlorite (NaOCl) (Kulik & Schoen, 1977). Ten kernels were plated on the agar in 90 mm petri-dish and five such petri-plates were incubated at 20-22 °C for 5 to 8 days. Macroscopic and microscopic examinations were made for cultural and morphological characters after the incubation period (Ellis, 1971, 1976; Ahmed & Reddy, 1983; Samson *et al.* 1996; Hunter & Barnet, 1998).

Assessment of mycoflora on sorghum grain in Alemaya, eastern Ethiopia, prior to storage

The survey was carried out in Alemaya district of East Hararghe during the 1998/99 crop-season. The district receives an annual precipitation of 800 mm with mean annual atmospheric temperature of 16 °C, and mean minimum and mean maximum of 9.3 and 23 °C, respectively (Brhane & Yilma, 1977; Yilma & Abebe, 1984; Tamirie, 1986). Grain samples were collected from three plots each in ten peasant associations in the district at three sampling occasions. The survey peasant

associations (PAs) were Adale Oltaa, Biftu Gedda, Damota Jalela, Effa Bate, Effa Oromyia, Finkile/Becheke, Gobie Selama, Haro Adi, Meda Belina, and Tinike (II).

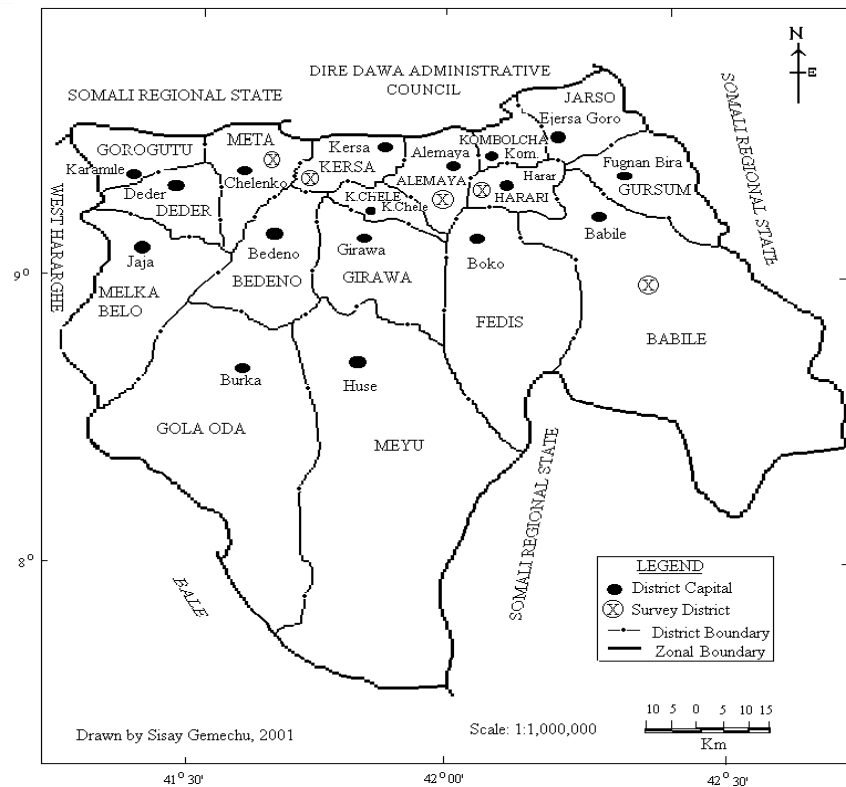


Figure 2. East Hararghe zonal administrative sub-division showing survey districts.

The sorghum types under the survey included *muyra* and *fendisha*. The sampling stages were: first sampling occasion at pre-harvest after full grain maturity; the second sampling after harvesting at the pile; and the third sampling at threshing time but prior to grain storage. Sorghum heads were taken for analyses in the first and second samplings separately while grain was collected in the third sampling in cloth bags. Grain moisture contents were measured using a moisture metre. Seed germination tests were conducted using standard procedures (ISTA, 1985, 1996; Mathur & Jørgensen, 1992). Four hundred seeds per sample were divided into four parts, i.e. 100 seeds per replication and were tested on germination paper in formica flats. After watering with distilled water, the flats were wrapped with thin transparent plastic to avoid moisture loss through evaporation. Germination was recorded 6 and 10 days after planting and seeds were defined as 'germinated' either when the plumule, radicle or both were visible (López & Christensen, 1963; Christensen, 1969, 1970).

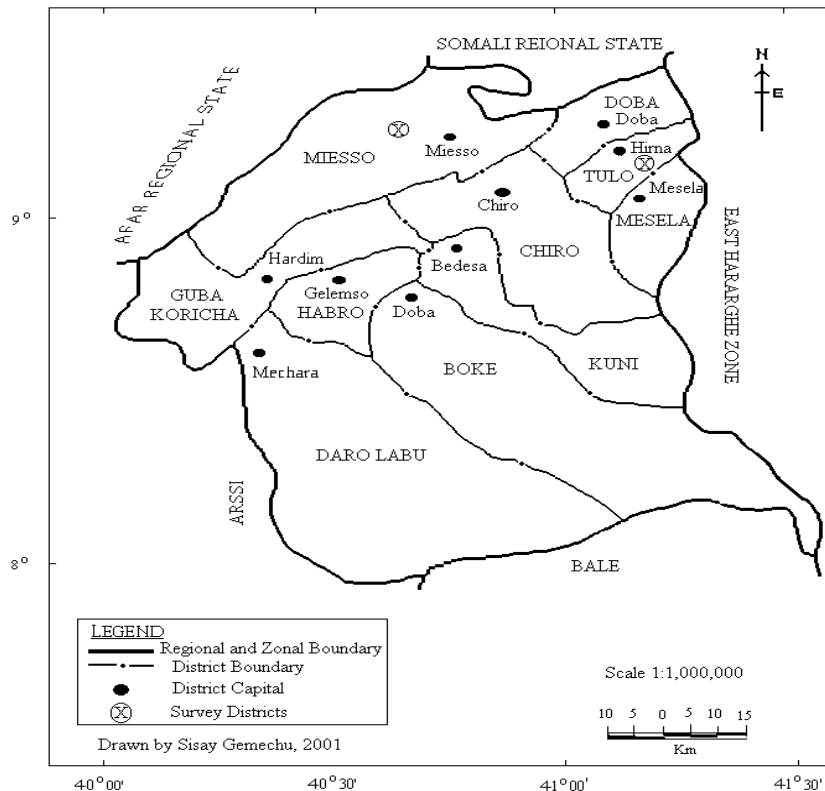


Figure 3. West Hararghe zonal administrative sub-division showing survey districts.

The microflora associated with the grain were cultured on potato dextrose agar (PDA) by plating surface-disinfected grains (De Tempe, 1970; Neergaard, 1973; Sheppard, 1979; Copeland & McDonald, 1995; Samson *et al.*, 1996). Five petri-plates, each with ten kernels per sample, were incubated at 20-22 °C for 5-8 days. Petri-plates were incubated for additional 5-7 days to detect late appearing and slow sporulating fungi. The number of infected grains out of 50 kernels per sample, i.e. 150 kernels per PA, and the corresponding colony frequencies were counted after the incubation period. Macroscopic and microscopic observations were made in the identification job (Malone & Muskett, 1964; Nelson, Toussoun & Marasas, 1983; Singh *et al.*, 1991; Zean *et al.*, 1994) and some isolates were also sent to CABI Bioscience, UK, for confirmation/identification work.

Above-ground bin and underground pit experiment at Alemaya University

The experiment was conducted at Alemaya University located 1980 m above sea level from March 2000 to February 2002. The sorghum, *long red muyra*, required for the experiment was produced at the Alemaya Research Site (Raare) on campus.

The treatments included:

- 1) Above-ground bin lined with plastic
- 2) Pit lined with cement plaster plus plastic
- 3) Pit lined with cow-dung plus plastic
- 4) Soil pit without any lining material

The above-ground bin was constructed using the general design by Sasakawa Global 2000 (1997). The underground storage pits were prepared following the designs described by Gilman (1968) and Boxall (1974). The treatments were arranged in randomized complete block design (RCBD) with three replications. The storage structures were lined with plastic with the exception of the soil pits and the required grain was poured in each store type and sealed. A thermometer probe was installed in each storage structure before sealing to monitor the granary temperature from outside three times a day at 0815, 1315 and 1715 GMT.

Grain samples were removed with a double sleeve sampler at two-month intervals by opening the bins and pits inserting the spear from grain top to the bottom. Several grain scoops from each bin or pit were bulked on separate bin or pit basis. The grain moisture content was recorded using a moisture tester. The grain bulk density was measured using hectolitre weight (Harris & Lindblad, 1978). Seed germination was performed using 400 seeds divided into four parts with 100 seeds per replicate (ISTA, 1985, 1996; Mathur & Jørgensen, 1992). The kernels were sown on two layers of germination papers in a formica flat and made moist by sprinkling distilled water. The flats were wrapped with transparent plastic to maintain high relative humidity and kept on a laboratory table at 20-22 °C. Germination was counted eight days after planting.

Five replicates of ten surface-disinfected grains each were plated on malt extract agar containing 7.5% NaCl in 90 mm petri-dish to cultivate the associated microfungi (Boller & Schroder, 1974; Mathur & Singh, 1992; Prasad, 1992b; Samson *et al.*, 1996). The petri-plates were incubated at 20-22 °C for 5-8 days. Macroscopic and microscopic examinations were made to identify the microfungi. Laboratory manuals and reference keys were used in the identification works (Kozakiewicz, 1989; Watanabe, 1994; Samson *et al.*, 1996; Warham, Butler & Sutton, 1997; Hunter & Barnett, 1998; Pitt & Hocking, 1999).

Chemical component analyses of stored sorghum grain

Sorghum grain sampling

Four subsequent batches of grain samples were collected from seven selected districts of East and West Hararghe as well as nine batches from the replicated storage experiment at Alemaya University. The districts that represented lowland, intermediate and highland agro-ecological zones included Alemaya, Babile, Chelenko, Hundenie, Kersa, Mieso and Tulo (Figure 2, 3). Twenty-eight underground pits, i.e. four pits in each district, were selected for sampling at two-month intervals during February to August in 2001. The local sorghum types and mixtures in the samples included *bedukagne* (Babile), *bedukagne-masugi* (Babile), *cherchero-muyra* (Kersa), *danga-muyra* (Kersa), *dasle* (Tulo), *fendisha* (Alemaya, Tulo),

fendisha~muyra (Alemaya, Chelenko, Kersa), *hamidiyie* (Chelenko), *masugi* (Babile, Miesso), *masugi-sarudie* (Miesso), *muyra* (Alemaya, Chelenko, Kersa), and *wegare* (Hundenie, Tulo). The samples were sent for analyses at the International Livestock Research Institute (ILRI) in Addis Ababa. Similarly, grain samples were taken during March 2000 to August 2001 from *long red muyra* sorghum stored in the above-ground bin, cement and dung pits all lined with plastic, and from soil pit without lining material in three replications at Alemaya University. Thus the nine batches collected in the test period were sent for analyses at the ILRI. All samples were stored at 4 °C until analyses and air-dried at 60 °C to remove excess moisture before analyses.

Chemical analyses

The Analytical Services Laboratory Department of ILRI did the chemical component analyses of the sample batches collected both from the districts of Hararghe and from Alemaya University using standard analytical procedures (Van Soest & Robertson, 1985; AOAC, 1990; Mebrahtu & Tenaye, 1997). The chemical components analyzed included dry matter (DM), ash, organic matter (OM), nitrogen (N), crude protein (CP), and soluble carbohydrate (SCHO) contents.

Statistical analyses of research data

Microsoft Excel software programmes were used in the calculations of treatment means and summary tables presented wherever required. The general linear models (GLM) procedure of SAS statistical software programmes was applied in the analyses of variances (ANOVA) and parameter estimates of the data on pit temperature, relative humidity, grain moisture, bulk density, thousand seed weight, seed germination and chemical components. Poisson regression was used in the analysis of frequency of *Penicillium* species over time. Treatment means comparisons were made using the least significant difference (LSD) method. In the prediction of the granary temperature and grain moisture, storage period (in days) was transformed by calculating $\sin(2\pi \cdot \text{DayN}/365)$ and $\cos(2\pi \cdot \text{DayN}/365)$ to investigate the cyclical variations within the data (Yuen *et al.*, 1994). The grain weight losses were calculated using the thousand grain mass (TGM) method developed by Proctor & Rowley (1983):

$$\% \text{ weight loss} = [(M_1 - M_x) \cdot 100] / M_1$$

where

M_1 = thousand grain mass (TGM) at the beginning of the study
 M_x = the TGM of grain on occasion 'x'

The percentage contents of chemical components for grain samples from seven districts of Hararghe and for samples from the replicated experiment at Alemaya University were estimated using standard procedures (AOAC, 1990; Mebrahtu & Tenaye, 1997). Figures were drawn with the help of the Microsoft Excel, MS Paint and MS Paint Pro-5 computer software programmes.

Results

Pit environment, grain quality and associated mycoflora in Hararghe districts

Farmers in the selected survey districts stored their sorghums in the traditional underground pits that were cone-shaped. The average depth of the pit was 165.8 cm with 62.1 cm mouth diameter and 152.0 cm bottom diameter (Table 1). None of the visited pits were properly lined with any material. The effects of sorghum type were confounded with geographic location (district) effects and, as a result, the degrees of freedom for the interaction were so few with reference to the dependent variables (pit temperature, grain moisture, relative humidity, etc.). This was because only two or a few of the sorghum types were grown in more than one location. Districts and their interaction with storage period strongly influenced granary temperature in the pits. Storage period did not significantly ($P>0.05$) affect the pit temperature. District and storage period had significant effect on the pit relative humidity. The storage pits in the lowlands had higher granary temperatures than the pits in the highlands. Similarly, pits in the lowlands had higher mean relative humidity ($>73\%$ r.h.) than pits in the highlands ($\leq 64\%$ r.h.). Relative humidity increased over time in the storage pits.

Table 1. *Dimensions and standard deviations of traditional underground storage pits in seven districts of East and West Hararghe, eastern Ethiopia*

District	Mean dimensions (cm) \pm standard deviation ¹					Total depth ²
	Mouth Diameter	Rim width	Rim height	Neck depth	Bottom diameter	
Alemaya	61.3 \pm 8.5	25.3 \pm 7.6	19.8 \pm 5.6	36.3 \pm 9.6	178.3 \pm 35.7	178.8 \pm 46.1
Babile	53.8 \pm 7.5	18.8 \pm 2.5	16.3 \pm 4.8	41.3 \pm 7.4	125.8 \pm 25.3	145.0 \pm 21.6
Chelenko	55.0 \pm 5.8	31.3 \pm 6.3	24.0 \pm 8.0	43.8 \pm 5.5	142.3 \pm 21.8	143.3 \pm 35.5
Hundenie	67.5 \pm 11.9	22.5 \pm 2.9	30.0 \pm 8.2	51.3 \pm 5.8	180.0 \pm 13.5	189.5 \pm 14.2
Kersa	68.8 \pm 7.5	33.8 \pm 18.9	26.3 \pm 9.8	42.8 \pm 9.1	147.5 \pm 44.1	149.5 \pm 30.2
Miesso	64.0 \pm 4.9	25.5 \pm 7.6	25.0 \pm 5.8	50.0 \pm 7.1	147.5 \pm 33.0	180.0 \pm 54.2
Tulo	64.5 \pm 9.0	30.0 \pm 13.5	31.3 \pm 14.3	42.3 \pm 9.8	141.5 \pm 18.6	174.5 \pm 44.2
Range	45.0-80.0	15.0-50.0	10.0-50.0	20.0-60.0	100.0-210.0	115.0-260.0
Mean	62.1 \pm 9.0	26.7 \pm 10.2	24.6 \pm 9.1	43.9 \pm 9.4	151.9 \pm 31.9	165.8 \pm 37.8

¹ Means are averages of four pits per district and are followed by standard deviations (SD)

² Total pit depth is the height from top of the neck depth to the bottom of pit including the empty space above the grain

District, storage period and their interactions had strong effects on grain moisture contents, moisture increasing with increase in storage period. The grain moisture content varied from district to district. The mean grain moisture content was higher than 15% m.c. in the survey period across the districts (I) as well as at Alemaya University (III). The grain bulk density was influenced by district, storage period and their interactions. It had a negative correlation with storage period. The grain weight loss varied from district to district. On average, the grain weight loss varied from 2 to 13% in the districts in Hararghe during the study period. Percentage grain weight loss had a positive correlation with granary temperature, relative humidity, and grain moisture contents. Districts, storage

period and their interaction had strong effect ($P \leq 0.05$) on seed germination. Reduction of germination was higher in the lowlands than in the highlands. Percentage germination, seedling heights and weights showed negative correlation with storage period. *Aspergillus* species were the dominant storage fungi associated with stored sorghum in all lowlands, intermediate and highlands. Frequencies of *Penicillium* species were higher in pits located in the highlands than in the lowlands. Grain moulding was more intense on the surface grain portion than the grain in the lower or bottom portion of the soil pit in the districts (I). A similar moulding trend was observed at Alemaya University (III).

Mycoflora association with grain during pre-harvest and prior to storage

The moisture contents of grain samples from the ten peasant associations varied between 11.1 and 12.7% during the sampling occasions at pre-harvest, post-harvest and after threshing. Percentage germination at the pre-harvest samples was lower than both at the stack and threshing occasions. There was no significant difference ($P > 0.05$) in germination among samples from different peasant associations at the same sampling occasion. Mean germination in samples of all three occasions was higher than 85%. Kernel infection by microfungi, as assessed visually, ranged between 2.1 to 6.8% during the three survey occasions. *Alternaria alternata* (Fr.) Keissler, *Cladosporium cladosporioides* (Fr.) de Vries, *Fusarium moniliforme* Sheld. and other *Fusarium* and *Phoma* species were the dominant mycoflora associated with the grain in the sampling occasions. Trace colonies of *Aspergillus candidus* Link, *A. ochraceus* K.Wilh., *Eurotium amstelodami* L. Mangin, *Penicillium aurantiogriseum* Dierckx, *P. chrysogenum* Thom and *P. glabrum* (Wehmer) Westling were detected in samples collected from some survey sites in the Alemaya district prior to grain storage (II).

Impact of storage methods on pit environment and sorghum grain quality

The difference in temperature among the store types (bin, cement, dung and soil pits) was statistically significant ($P \leq 0.05$). The soil pits with no-lining material were the warmest (mean monthly maximum 29.6 °C) of all storage environments and the above-ground bins maintained the lowest temperature (mean monthly maximum 21.9 °C) in a storage period of 17 months. The temperature in the cement- and dung-lined pits did not differ significantly. Recording time of day, cyclic factors and length of storage period also had strong effects on storage temperature. The grain bulk density decreased over time at a rate of 5.18 g-litre⁻¹ per month in the samples from the soil pits while the change in samples from the bins, cement and dung pits was not significant. Store type, storage period and cyclic factors had strong effects on grain moisture contents. The mean moisture content of grain samples from the soil pits was higher than the mean values for the bins, cement and dung pits for storage period of 15 months. On average, the mean moisture content of samples from the soil pits reached as high as 17%. The mean values for the bin and non-soil pits were below 13% mc. Percentage seed

germination was negatively correlated with storage period of samples from the soil pits at Alemaya University, decreasing at a rate of 6% per month (III), as well as in Hararghe districts (I). There was no significant reduction in germination (>90% germination) of samples from the non-soil pits while germination for the soil pits decreased to 12% in 13 months.

Some field fungi, including *Alternaria alternata*, *Cladosporium cladosporioides* and *Fusarium moniliforme*, were associated with grain samples from the above-ground bins and underground pits. The most prevalent storage fungi detected in association with the grain, especially in samples from the soil pits, included *Aspergillus candidus*, *A. flavus*, *A. glaucus*, *A. niger*, and *Penicillium aurantiogriseum*. The colony frequencies of these storage fungi were higher in samples from the soil pits than in samples from the other store types. The surface portion of grain in soil pits and that in contact with the walls was severely moulded and discoloured while the grain in the bins, cement and dung pits was fresh for the same storage period (III). The same situation was observed in the soil pits in Hararghe districts (I).

Effects of storage methods, storage time and agro-ecological zones on chemical components

1. Chemical components of sorghum grain from Hararghe districts (IV)

Districts significantly affected the organic matter and crude protein contents. Only storage period showed a significant effect on dry matter contents of samples from districts in Hararghe. Storage period had no significant effect on organic matter and crude protein contents. Districts and storage period had strong influence ($P \leq 0.05$) on soluble carbohydrate (SCHO) contents. On the average, the SCHO content decreased from 2.4 to 1.2% in the seven-month storage period.

2. Chemical components of grain stored in bins and pits at Alemaya University (IV)

Store types (bin, cement, dung and soil pits) had strong effects on the organic matter and soluble carbohydrate contents of grain; but they had no significant effects on crude protein contents. Storage period influenced the contents of all chemical components analyzed. The organic matter and soluble carbohydrate contents of samples from the soil pits were significantly different from samples taken from the above-ground bins and the other non-soil pits. The organic matter decreased from 97.8 to 91.6% in grain samples from the soil pit while the soluble carbohydrate decreased from 2.4 to 0.97% in 17 months.

Discussion and Conclusions

The underground pit used in Hararghe was found to be unsuitable for safe grain storage. It raised the granary temperature and grain moisture content favouring development of micro-organisms and pests over storage time. The migration of moisture from the surrounding soil walls into the grain was the main cause for

elevation of grain moisture. Enhanced respiration by organisms further elevated both the pit temperature and relative humidity. This self-accelerating process aggravated grain deterioration making the grain unfit for human consumption. The grain stored in the soil pit without any lining material decreased in its bulk density, thousand seed weight, percentage germination, and grain weight. Overall vigour was also reduced since the resulting seedling height and weight also decreased. The organic matter and soluble carbohydrate contents decreased over time in grain samples from the soil pits. Grain stored in above-ground bins, cement and dung pits, all lined with plastic, showed no quantitative and qualitative deterioration. Replacement or modification of the underground pit is desirable to maintain the grain quality for a reasonably longer period.

District and storage type significantly affected pit temperature (I, III) and relative humidity (I). Soil pit temperature and relative humidity were higher in the lowlands than in the highlands. Also, granary temperature and relative humidity of soil pit were much higher than those in the above-ground bins as well as modified underground pits. Grain moisture was strongly affected by district, store type, cyclic factors and storage period (I, III). Grain moisture generally increased with storage time in the soil pits while it remained within the safe storage levels in the bin and non-soil pits (III). The high levels of temperature, relative humidity and moisture encountered in the soil pits usually favoured insect infestation and invasion by storage fungi accelerating grain spoilage. Grain moisture content levels higher than 13% are favourable for storage fungi attacking sorghum (Christensen, 1967). The storage fungi can produce mycotoxins such as aflatoxins on sorghum grains with high moisture contents. For instance, a significant level of 37.6 ppb aflatoxin B₁ has been recorded on sorghum grain kept in a local store (Misra, Singh & Tripathi, 1980). This is beyond the tolerance level of 20 ppb (Bullerman, 1979).

The reduction in grain weight, percentage seed germination, organic matter and soluble carbohydrate contents (I, III, IV) was associated with poor grain storage practices accompanied by insect infestations and storage fungal invasion. Frequencies of storage fungi increased over time in such poor storage structures. Contamination of grain by storage fungi could occur during pre-harvest, at harvest, threshing, winnowing and transportation due to poor sanitary practices and could explode to damaging levels in the storage period (II). *Aspergillus* species such as *Aspergillus candidus*, *A. flavus*, *A. glaucus*, *A. niger* and *A. ochraceus*, and *Penicillium* species including *Penicillium aurantiogriseum* were associated with moulding grain under poor storage in the soil pit. The absence of any lining material in the underground pit and direct leakage of rainwater into the pit exposed the grain to deleterious conditions. There are similar reports that grain deterioration has been associated with storage fungi under poor storage environments (Merono, Lopez & Christensen, 1965; Christensen & Kaufmann, 1969; Tuite & Foster, 1979; McLean & Berjak, 1987; Prasad, 1992a). Such grain would have low grain weight and poor nutritional value and could be rejected for this very reason. There is also evidence that infestation by storage pests can aggravate the grain damage (Sinha & Sinha, 1992).

Countries in the Sub-Sahara domain, including Ethiopia, frequently suffer from disturbances of the regular patterns of rainfall due to climatic changes that negatively influence crop production in the field. Besides, the use of poor storage methods often results in various post-harvest grain losses and aggravates the grain shortage situation, thus leading to difficulties in feeding the ever-increasing human population. The unmodified traditional underground storage pit belongs to the category of such poor storage methods. If we calculate the post-harvest grain loss multiplying the annual total production 222850 t in Hararghe by the estimated grain weight loss 13% (I), the sorghum grain loss would be 28970 metric tonnes. This amount of grain would feed 93450 people each year, assuming 0.31 metric tonne of grain is required per person per year (Mallya, 1992). The evaluation and introduction of improved grain storage methods would, to some extent, reduce the grain losses due to insect pests and storage fungi, contributing an impetus to the fight against the alarming human hunger and starvation. With the help of the data generated in this thesis, we can make the following conclusions.

- ▶ The sorghum heads are left on the bare soil to dry in the sun for some days at harvesting and contamination by microfungi can possibly take place (II). Piling and threshing of sorghum heads on non-cemented ground is a possible source of grain contamination by storage fungi. Farmers use the same ground for heaping the heads and threshing year after year. This practice can allow the storage fungi to gradually build up in the site and remain for contamination in the subsequent years. The use of contaminated sacks or other used containers for grain transportation can serve as a source of inoculum. Therefore, sanitation of the threshing floor and application of other related sanitary practices during harvesting, heaping, and transportation should be given due attention to reduce grain contamination prior to storage.
- ▶ The traditional underground pit environment is unsuitable for safe grain storage. Moisture ingress from the surrounding soil into the grain elevates the grain moisture content and enhances respiration by insect pests and micro-organisms. This situation further increases the granary temperature, relative humidity and grain moisture creating favourable conditions for storage fungi leading to grain spoilage. Severely moulded grain loses its bulk density, grain weight, percentage germination and other inherent qualities (I, III, IV). Modification of the underground pit by lining with plastic or replacing with an improved above-ground bin can avert biodeterioration and improve grain quality and storability. Such a storage structure would maintain grain moisture and temperature at lower levels that do not favour development of spoilage organisms.
- ▶ The extent of grain weight loss of sorghum stored in the underground pit varies with original grain conditions, degree of infestation by insect pests, invasion by storage fungi, geographic location, storage period, soil type, pit environment and pit sanitation. On the average, the grain weight loss for Hararghe is estimated at 13% in 7 to 8 months storage period, reaching as high as 24%. Similarly, seed germination decreased from 83 to 27% on average for the same storage period (I). This level of grain damage can affect the economy and nutrition of the farming community and is intolerable.

► In addition to the quantitative grain losses, infestation by insect pests and invasion by storage fungi can result in changes in the percentage chemical components and lower the potential nutritive value of the sorghum grain. The organic matter and soluble carbohydrate (SCHO) contents are negatively correlated with storage period of grain stored in the underground pit (IV). The reduction in organic matter and SCHO contents is associated with poor grain storage and invasion by storage fungi. Also, the storage fungi that cause grain moulding may produce mycotoxins that bring about health hazards if such grain is consumed excessively. The change in organic matter and SCHO contents of grain stored in the above-ground bin, cement and dung pits lined with plastic is not significant.

Future Research Priorities

There are drawbacks of the traditional underground pits (I, III, IV) such as grain deterioration, grain soiling and difficulty during grain removal. In this study, only one type of above-ground bin was compared with underground storage pits. Designing and evaluating other types of above-ground storage structures would provide farmers with options for selection to suit their needs with respect to the amount of grain produced and low cost of construction. Comparative studies of lining methods of the above-ground bins themselves also help identify the lining materials that would allow longer grain storability and maintenance of grain quality. We used grass thatching on the corrugated iron sheet of the bin roof to insulate the heat due to radiation in this study. Other low cost bin building materials such as wooden sticks, bamboo, bricks, concrete blocks, etc, roofing and insulating materials can be tested taking into account the purchasing capacity of the peasants.

There is lack of adequate information on the toxigenic storage fungi associated with sorghum grain stored in the underground pit. The type of storage fungi responsible and the corresponding mycotoxins produced need identification. The extent of mycotoxins produced and conditions favouring their productions require further investigations. Also, the effects of the mycotoxins on human beings and animals and the tolerable toxigenic levels of the mycotoxins demand due attention. The simultaneous and interwoven occurrence of storage pests and storage fungi in association with stored grain creates difficulties in estimating contribution of each group to reduction in grain bulk densities, weight loss, percentage chemical components, and increase in storage temperature and grain moisture. Distinction should be made through inoculated and controlled experiments to know the role played by the separate organisms. Quantification of grain losses during harvesting as fall-off, threshing and transportation can give a hint whether the losses are significant for future attention.

Farmers in Hararghe grow different local sorghum types for various reasons. One reason often mentioned by farmers is variation in resistance to storage pests and grain moulding. This must be proved experimentally. The collection of the local sorghums and testing them together with cultivated varieties can help

identify materials having variability in resistance and possibility for longer storability. Farmers also use the leaves of some plants as grain protectants against insect pests. The collection and evaluation of such botanicals may be useful in the search for effective methods of environmentally safe post-harvest control. In the temperate countries, the yeast *Pichia anomala* (Hansen) Kurtzman is being tested as an effective biocontrol agent against the storage fungi such as *Penicillium roqueforti* Thom on high-moisture cereals such as wheat and barley. The search for such yeasts to be used against storage fungi of crops in the tropics might be of vital importance in the grain management system.

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